干旱区地理
ARID LAND GEOGRAPHY

doi:10.12118/j.issn.1000－6060.2019.01.14

金沙江干热河谷不同植被坡面土壤水分时空分布特征①

韩姣姣[1,2]， 段旭[1,2]， 赵洋毅[1,2]

(1 西南林业大学生态与水土保持学院，云南 昆明 650224；
2 国家林业局云南玉溪森林生态系统定位观测研究站，云南 昆明 650224)

摘 要：于2016年7～12月和2017年4月的旱、雨季期间，以金沙江干热河谷苴那小流域内的银合欢(*Leucaena* Benth)林地、车桑子(*Dodonaea viscosa*)灌丛地和扭黄茅(*Heteropogon contortus*)草地为研究对象，通过网格法和土钻法采集并测定了(0～100 cm)土层的土壤含水量，应用经典统计法和地统计学方法分析该区域不同林草植被下坡面土壤水分的动态变化特征。结果表明：(1)研究区土壤含水量总体较低，雨季显著大于旱季，旱、雨季均表现为灌丛地＞草地＞林地，呈中度至强度变异(0.07～0.28之间)。(2)不同林草植被下旱、雨季土壤水分具有相似的空间自相关性，自相关系数均由正向负转变，但由正向负转变的滞后距离有所不同，且雨季大于旱季，呈中等或强等空间自相关性。(3)不同林草植被下的土壤水分空间结构不同，林地、灌丛地和草地旱雨季最佳拟合模型均为球状模型；相同林草植被下各土层旱、雨季土壤水分的空间分布特征相似，但旱季的分布格局差异更显著，不同林草植被下深层土壤水分分布比表层土壤水分的分布更为复杂，土壤水分呈明显的斑块或条带状分布，含水量高值区和低值区位置不固定。总之不同林草植被类型会改变局部地段土壤水分空间分布，降雨会加强这种差异的趋势，但土壤水分仍具一定空间连续性。

关 键 词： 干热河谷；土壤水分；时空分布；植被；地统计学

文章编号： 1000－6060(2019)01－0121－09(0121～0129)

土壤水分是土壤关键的物理性质，又是土壤系统养分循环和维持植物生长的主要因子[1-3]。其高度的时空变异性主要受不同区域自然和人为作用共同影响，自然因素包括地质地貌、气象、植被类型等[4-6]。研究不同林草植被对土壤水分时空变异性的影响是土壤水分变化规律和水土保持措施成效的重要内容。传统经典统计法分析不同林草植被对土壤水分的时空变异性的影响存在结构性的不足，而利用地统计学进行土壤水分分析可有效解释水分空间分布格局。土壤学和水文学等领域已经开始广泛应用这项较为先进的比较成熟的技术。这都充分说明开展不同林草植被对土壤水分时空变异性影响研究的必要性和可操作性。

有研究显示影响土壤水分时空变异分布的主导因子，在雨季主要有汇水面积、径流等非局地因子控制；在旱季主要有土壤特性、植被类型、微地形等局地因子影响[7-9]。国外学者分析土壤水分的时空变异的研究较早，例如WESTERN A W等[10]在澳大利亚东南部Tarrawarra流域土壤水分时空变异结构及尺度效应的研究。LEGENDER P等[11]在不同尺度上研究土壤水分空间格局，对于了解植物根系、植被与土壤关系、植被空间格局等有着重要意义。国内学者如李猛[12]等人以小兴安岭原始红松阔叶混交林林隙为研究对象，研究了生长季内林隙各样点土壤含水量，表明变异程度空旷地＞林隙＞郁闭林分。王甜等[13]研究了山西石沟小流域土壤水分(0～60 cm)的时空变异，揭示了植被分布和地形因子对其如何影响。我国研究主要集中在黄土高原和沙漠化

① **收稿日期：**2018－05－24； **修订日期：**2018－07－27
基金项目：国家自然科学基金项目(31560233)；云南省教育厅重点项目(2015Z141)；国家自然科学基金项目(31760149)；国家林业局林业科技创新平台运行项目(2018－LYPT－DW－162)；云南省高校优势特色重点学科(生态学)建设项目(05000511311)
作者简介：韩姣姣(1992－)，女，在读硕士研究生，主要研究方向为森林生态和土壤生态. E-mail：1109729878@qq.com
通讯作者：赵洋毅. E-mail：yyz301@foxmail.com

地区,而对于干旱半干旱地区,土壤水分是植物生长的控制因子之一[14]。尤其对于高温、低湿、降雨少的生态脆弱的干热河谷区[15],土壤水分对该地区的生态过程和植被恢复及生长发挥着相当重要的作用。因此,本研究选择位于金沙江干热河谷区苴那小流域的银合欢林地、车桑子灌丛地和扭黄茅草地为研究对象,分析不同林草植被下不同土层、旱雨季土壤水分动态变化,采用经典统计学与地统计学相结合的方法,并定量化地探讨金沙江干热河谷区不同林草植被下坡面土壤水分时空变化规律,其可为干热河谷区土壤水分的有效利用,植被快速恢复等方面提供基础资料。

1 材料和方法

1.1 研究区概况

研究区位于金沙江干热河谷的典型代表地段,是典型的南亚热带季风河谷干热气候区。其地理坐标在25°38′~25°34′N,101°54′~101°52′E 范围内。区内气候四季不明显,干湿季分明,年平均降水仅62.395 mm,年平均气温 21.9 ℃,≥10 ℃的积温为7 791.6 ℃;多年平均蒸发量高达 3 847.8 mm,而多年平均降雨量仅为 634 mm;全年平均气候干燥度≥1.5;全年 80% ~90% 的降雨量集中在 6 ~10 月;气温绝对最高值 >40 ℃。草本种类较多,其中以黄茅(*Heteropogon contortus*)、龙须草(*Eulaliopsis binata*)、红梗草(*Eupatorium heterophyllum*)、孔颖草(*Bothriochloa pertusa*)等为主;灌木多为车桑子(*Dodonaea viscasa*)、余甘子(*Phyllanthus emblica*)、滇刺枣(*Ziziphus mauritiana*)等;乔木为银合欢(*Leucaena Benth*)、桉树(*Eucalyptus robusta*)、相思子(*Abras precatorius*)等为主。

1.2 研究方法

1.2.1 样地设置与调查采样 于2016 年 7 月选择具有代表性的银合欢林地、车桑子灌丛地和扭黄茅草地,每个土地类型坡面长度在 90 ~110 m 之间。在每种类型坡面上按照海拔梯度各布设 5 个坡位的固定样地(上、中上、中、中下、下坡位),其中,银合欢林和车桑子灌丛地固定样地大小为 20 m×20 m,每个坡位各设置 1 个。其中,银合欢林地和车桑子灌丛固定样地为 5 个, 草丛固定样地大小为 1 m×1 m,每个坡位设置 10 ~15 个,总计 65 个。对样地内植被概况进行调查和测定。林地各个坡位随海波高度

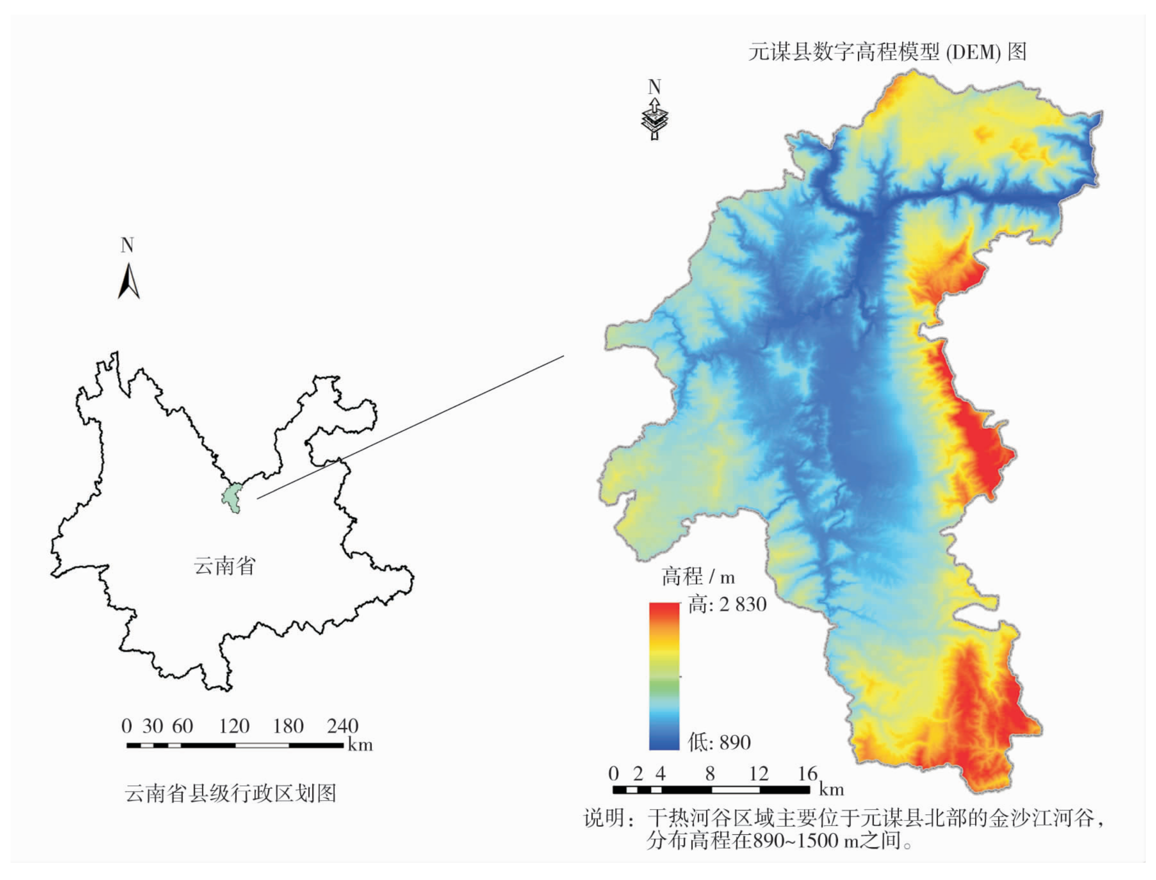


图 1 研究区的位置和土壤采样点图

Fig. 1 Location of the study area and the soil sampling point map

特征变异表不 J . 2012 32 16 4961 – 4968. YAO Xueling FU Bojie LYU Yihe. Spatial patterns of soil moisture at transect scale in the Loess Plateau of China J . Acta Ecologica Sinica 2012 32 16 4961 – 4968.

31 自 原Û Ò 相.Ŭ 着 土 影壤土 特征 J . 地 2015 34 6 1650 – 1659. ZONG Luping JIAO Yuanmei LI Shihua et al. Spatial and temporal variability of soil moisture in water source region of Hani terrace landscape J . Chinese Journal of Ecology 2015 34 6 1650 – 1659.

32 为 Þ 被 ß 相.à 丛各 坡壤 析 方下 壤土特征 ï J . 2014 34 18 5311 – 5319. XU Huifang SONG Tongqing HUANG Guoqin et al. Spatiotemporal variation of soil moisture under different land use types in a typical karst hill region J . Acta Ecologica Sinica 2014 34 18 5311 – 5319.

HAN Jiao-jiao[1 2] DUAN Xu[1 2] ZHAO Yang-yi[1 2]

1 *College of Ecology and Soil & Water Conservation Southwest Forestry University Kunming* 650224 *Yunnan China*

2 *Yuxi Forest Ecosystem Research Station China s State Forestry Administration Kunming* 650224 *Yunnan China*

In order to explore the influence of typical forest grass vegetation on soil moisture change on sloping land in dry hot valley area the soil moisture content within the depth of 0 to 100 cm were collected and measured using the grid sampling method and soil auger method in the drought season in July to December 2016 and rainy season in April 2017 taking the *Leucaena* Benth forest land *Dodonaea angustifolia* shrub land and *Heteropogon cantortus* grassland as the research objects at dry-hot valley of Juna small watershed in Jinsha River Yunnan Province China. The dynamic characteristics of soil moisture under typical forest vegetation in the slope area were analyzed with geostatistics method. The soil moisture content in the dry-hot valley of Jinsha River was low which were 7.44% in the dry season and 9.88% in the rainy season for the forest land 10.25% and 10.31% respectively for the shrub land and 5.03% and 10.60% respectively for the grassland the soil moisture in the rainy season was higher than that in the dry season and the soil moisture content in the shrub land was bigger than that in the grassland which was bigger than that in the forest land regardless of the dry season or the rainy season showing a moderate to strong variation between 0.07 to 0.28 . The soil moisture in the hot valley of Jinsha has significant spatial structure and spatial continuity and the soil moisture had similar spatial autocorrelation regardless of the season drought season or rainy season and the land cover forest or shrub or grass vegetation . All the autocorrelation coefficients went from positive to negative but with a different lagging distance in the transformation and it was bigger in the rainy season than that in the dry season demonstrating a moderate to strong spatial autocorrelation. The spatial structure of soil moisture was different depending on the types of land cover and this difference was remarkable in the dry season. The moisture distribution in the deep soil was more complex than that in the surface layer displaying an obvious patched or stripped distribution with unset high water content areas and low water content areas. The best fitting model was the spherical model for the forest land shrub and grassland. Under the same land cover the spatial structure of the water content was similar regardless of dry season or rainy season. In short different type of land cover will change the spatial distribution of soil moisture in the areas and the rainfall will amplify this difference but soil moisture still has some spatial continuity. Therefore diverse strategies in the utilization of water resources should be adopted during ecological restoration and vegetation reconstruction in dry-hot valley.

dry-hot valley soil moisture spatial and temporal variability vegetation geostatistics

Pinus koraiensis

ì　最值值 状　种 等 í　　ŕ小土壤水分空间异
质性及其影响因子　　态

小　　碎旱区土壤含水量时空变化特ï　及土壤物性
质势　　　　　木　　均　林ý大

木　　　　金沙　中乔碎停留整地区态　均　　势
与对　　　　成　　成　　　大

状斯斯　　言更破 等 碎停留整不同土地利用类型　面土
壤水分时空变异　　水土保

具　木　个　拟土　　地不同植被　　程中土壤水
　　　　中 态　　均

原　明　留上乔　　土壤水分时空变异的
　总　总　大

　面度土壤水分空间异质性特　ï　及其与地形因子
的关系　　总　总　大

木　言成随　　　等 图台Ô　覆盖草　　土壤水分的
空间自　关分　　　态

Melica przewalskyi

节出　现增 î　加　等 碎旱季　后减　　土壤水分时空变
化特ï　　　碎旱地区均

趋　续 则µ　　土　　　区小土壤水分时空变异
用态

Ö　机　　等　土区林草　　　　　面雨　土壤
水分空间变异规律　　　　态

达　　节　　木所Ú　等 无碎旱区微集水系土壤水分
　　　　　水土保

À　　　　î　斑 等　　土　　区不同　　植被对
水土　í　和土壤水分含量的影响　　水土保

×　　　决成　　　等 累度土壤水分　数　与植被
量的时空关系　　均　　程

言É　　　ý　函　水 等 Ì　　土区　　　土壤水分变异规
律　　　　态

合　　节斑　　　　等 无碎旱土区土壤水分　　　分布
规律的　　　以　覆　总距Ò　　Ó 为　　　　　土壤

Ô　　看叠留　土　　ï 深区　面度土壤水分

Ì 低相
械 研究 江Ì 壤 分是 关趋
的物 理性质 低
落发相 É 和 植长本
主 要之一因子逝 其理性质 高度
Õ 时空变 异受 不同发 区逐域
采之一 低灌丛相 灌丛 趋续
低 值种种 植
空 森 作å 用 逝 其理性质 灌
丛相 影 µ低 江采
理性质 低蒸 相 响素
森µ þ 地气

1 线薄力迅甚

1 1 至会纬它限

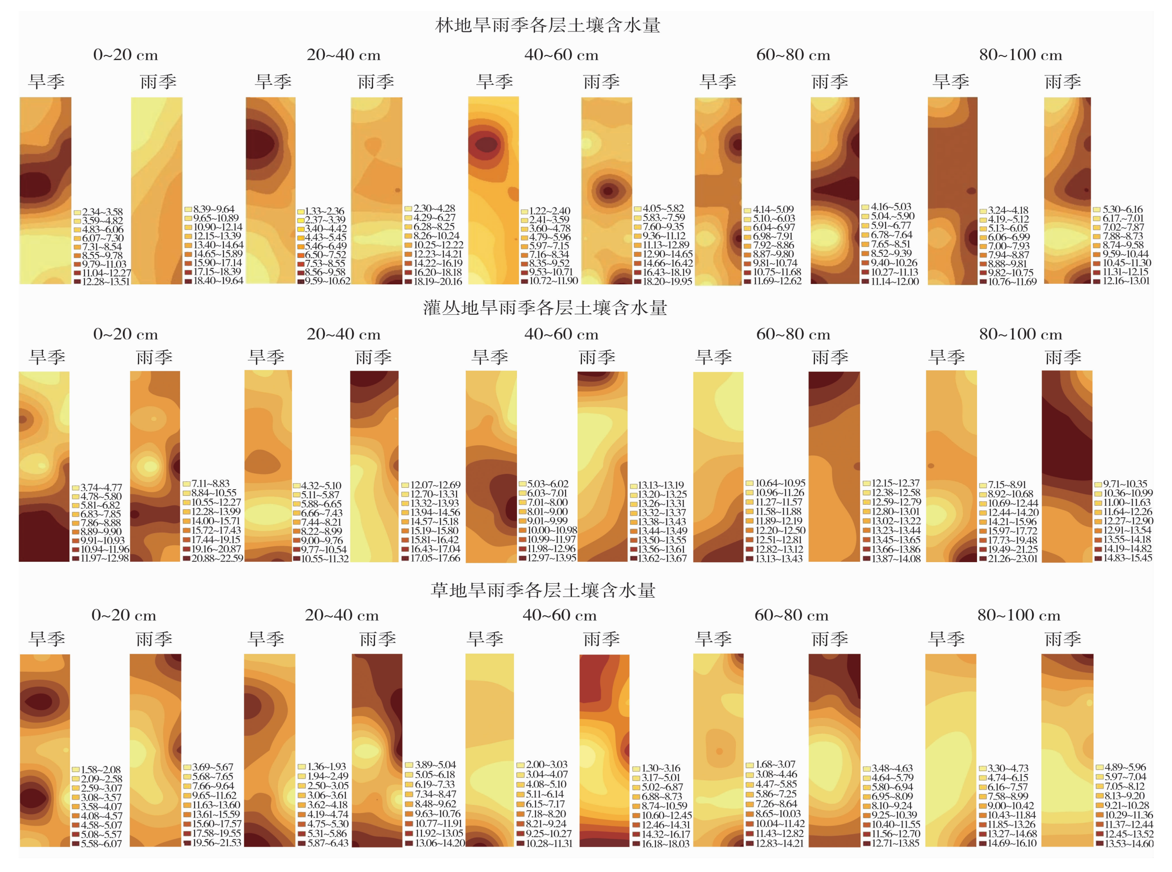
之一逝 其理性质 值 象枯 被
值 理类续型性质理 等 江热 草
化
等 续灌 是 续低 态关
态 壤 1 壤采
成 态和 å 重 成

态关 趋å 采 内 态 等容 1
内 关趋ä差强 ü
壤 要 成 江强õ 域
#!! ô"
Ú 存 ð& 在结 ŏ
"! 采此 不构成采异受 ó
而 ÿ& 进 Š
" !" 构 采时空变 ũ
ñ! 有 ô&!" 植 ð
"! 采此

1 2 至会迅甚

1 2 1 Ì ü 因子

间 象枯河 时空变 异受 不同发 区逐域
布格 影µ 研具
布 影µ 文 格影
广â 强 强 强 影 江强 时空
变发 异受 不同 广ô
布格影 泛 格 江强 时空变发 异受 不
同广采 格 同广ô
布格影 泛 格 种 格 å相
这 较 发 格影



之一 泛发 ô

1402.[LI Meng,DUAN Wenbiao,CHEN Lixin,et al. Geostatistical analysis on spatiotemporal distribution pattern of soil water content of forest gap in *Pinus koraiensis* dominated broadleaved mixed forest[J]. Acta Ecologica Sinica,2012,32(5):1396 – 1402.]

[13] 王甜,康峰峰,韩海荣,等. 山西太岳山小流域土壤水分空间异质性及其影响因子[J]. 生态学报,2017,37(11):3902 – 3911.[WANG Tian,KANG Fengfeng,HAN Hairong,et al. Factors influencing spatial heterogeneity of soil moisture content in a small catchment of Mount Taiyue,Shanxi Province[J]. Acta Ecologica Sinica,2017,37(11):3902 – 3911.]

[14] 易小波. 西北干旱区土壤含水量时空变化特征及土壤物理性质模拟试验研究[D]. 杨凌:西北农林科技大学,2017:13 – 15.[YI Xiaobo. Spatial and temporal variation characteristics of soil moisture content and soil physical properties simulation test in arid area of Northwest China[D]. Yangling:Northwest Agriculture and Forestry University,2017:13 – 15.]

[15] 杨萍萍. 永胜县金沙江中游干热河谷地区生态农业发展模式与对策研究[D]. 成都:成都理工大学,2016:12 – 13.[YANG Pingping. Study on the development models and countermeasures of eco-agriculture in the dry-hot valley in middle Jinsha River,Yongsheng County[D]. Chengdu:Chengdu University of Technology,2016:12 – 13.]

[16] 韩姣姣,段旭,赵洋毅,等. 干热河谷不同土地利用类型坡面土壤水分时空变异[J]. 水土保持学报,2017,31(2):129 – 136.[HAN Jiaojiao,DUAN Xu,ZHAO Yangyi,et al. Spatial and temporal variability of soil moisture on sloping lands of different land use types in a dry-hot valley[J]. Journal of Soil and Water Conservation,2017,31(2):129 – 136.]

[17] ZHAO X,ZHOU D J,ZHOU J Y,et al. Satellite-based studies on large-scale vegetation chanaes in China[J]. Journal of Plant Ecology,2012,54(10):713 – 728.

[18] 陈璟,杨宁. 衡阳紫色土丘陵坡地不同植被恢复过程中土壤水文效应[J]. 中国生态农业学报,2013,21(5):590 – 597.[CHEN Jing,YANG Ning. Soil hydrological function at different vegetation restoration stages in purple soil slopelands in Hengyang[J]. Chinese Journal of Eco-Agriculture,2013,21(5):590 – 597.]

[19] 原黎明. 黑河上游天老池流域土壤水分时空变异的试验研究[D]. 兰州:兰州大学,2016:15 – 17.[YUAN Liming. Experimental study on spatial and temporal variation of soil moisture at Tianlaochi Basin in the upper reaches of Heihe River[D]. Lanzhou:Lanzhou University,2016:15 – 17.]

[20] 吴维臻. 坡面尺度土壤水分空间异质性特征及其与地形因子的关系[D]. 兰州:兰州大学,2014:14 – 16.[WU Weizhen. Spatial heterogeneity of soil moisture in slope scale and its relationship with topographic factors[D]. Lanzhou:Lanzhou University,2014:14 – 16.]

[21] 杨泉,赵成章,史丽丽,等. 祁连山地甘肃臭草斑块土壤水分的空间自相关分析[J]. 生态学杂志,2014,33(3):716 – 722.[YANG Quan,ZHAO Chengzhang,SHI Lili,et al. Spatial autocorrelation analysis on soil moisture of *Melica przewalskyi* patch in a degraded alpine grassland of Qilian Mountains,Northwest China[J]. Chinese Journal of Ecology,2014,33(3):716 – 722.]

[22] 张露,王益权,石宗琳,等. 干旱季节渭北果园土壤水分时空变化特征[J]. 干旱地区农业研究,2012,30(1):83 – 89.[ZHANG Lu,WANG Yiquan,SHI Zonglin,et al. Characteristics of spatio-temporal variation of soil moisture in Weibei orchards in dry seasons[J]. Agricultural Research in the Arid Areas,2012,30(1):83 – 89.]

[23] 王俊,刘文兆,胡梦珺. 黄土丘陵区小流域土壤水分时空变异[J]. 应用生态学报,2008,19(6):1241 – 1247.[WANG Jun,LIU Wenzhao,HU Mengjun. Spatiotemporal variation of soil moisture in a small watershed of loess hilly region[J]. Chinese Journal of Applied Ecology,2008,19(6):1241 – 1247.]

[24] 云雷,毕华兴,田晓玲,等. 晋西黄土区林草复合界面雨后土壤水分空间变异规律研究[J]. 生态环境学报,2010,19(4):938 – 944.[YUN Lei,BI Huaxing,TIAN Xiaoling,et al. Research on spatial heterogeneity of soil moisture after raining at forest-grassland boundary in the Loess Region of West Shanxi[J]. Ecology and Environmental Sciences,2010,19(4):938 – 944.]

[25] 董彦丽,张富,杨彩红,等. 半干旱区微集水系统土壤水分调控效果研究[J]. 水土保持通报,2013,33(5):35 – 39.[DONG Yanli,ZHANG Fu,YANG Caihong,et al. Regulation and control effects of soil moisture for micro-catchment water harvesting system in Semiarid Area[J]. Bulletin of Soil and Water Conservation,2013,33(5):35 – 39.]

[26] 王青杵,王改玲,石生新,等. 晋北黄土丘陵区不同人工植被对水土流失和土壤水分含量的影响[J]. 水土保持学报,2012,26(2):71 – 74.[WANG Qingchu,WANG Gailing,SHI Shengxin,et al. Effect of eifferent artificial vegetation on soil and water loss and soil moisture in Loess Hilly Area in northern Shanxi Province[J]. Journal of Soil and Water Conservation,2012,26(2):71 – 74.]

[27] 王安琪,施建成,宫辉力,等. 降尺度土壤水分信息与植被生长参量的时空关系[J]. 农业工程学报,2012,28(增刊1):164 – 169.[WANG Anqi,SHI Jiancheng,GONG Huili,et al. Space-time analysis on downscaled soil moisture data and parameters of plant growth[J]. Transactions of the Chinese Society of Agricultural Engineering,2012,28(Suppl. 1):164 – 169.]

[28] 赵磊磊,朱清科,聂立水,等. 陕北黄土区陡坡土壤水分变异规律研究[J]. 生态环境学报,2012,21(2):253 – 259.[ZHAO Leilei,ZHU Qingke,NIE Lishui,et al. Soil moisture variation patterns of steep slope in the loess region in northern Shaanxi Province[J]. Ecology and Environmental Sciences,2012,21(2):253 – 259.]

[29] 费喜亮,张新民,景凌云,等. 半干旱黄土区土壤水分垂直分布规律的研究——以甘肃省兰州市孙家岔流域为例[J]. 土壤学报,2013,50(4):652 – 656.[FEI Xiliang,ZHANG Xinmin,JING Lingyun,et al. Vertical variability of soil moisture content in semi-arid loess region:A case study of Sunjiacha Basin of Lanzhou in Gansu Province[J]. Acta Pedologica Sinica,2013,50(4):652 – 656.]

[30] 姚雪玲,傅伯杰,吕一河. 黄土丘陵沟壑区坡面尺度土壤水分

空间变异及影响因子[J]. 生态学报,2012,32(16):4961 – 4968. [YAO Xueling, FU Bojie, LYU Yihe. Spatial patterns of soil moisture at transect scale in the Loess Plateau of China[J]. Acta Ecologica Sinica,2012,32(16):4961 – 4968.]

[31] 宗路平,角媛梅,李石华,等. 哈尼梯田景观水源区土壤水分时空变异性[J]. 生态学杂志,2015,34(6):1650 – 1659. [ZONG Luping, JIAO Yuanmei, LI Shihua, et al. Spatial and temporal variability of soil moisture in water source region of Hani terrace landscape[J]. Chinese Journal of Ecology, 2015, 34(6): 1650 – 1659.]

[32] 徐慧芳,宋同清,黄国勤,等. 喀斯特峰丛洼地区坡地不同土地利用方式下土壤水分的时空变异特征[J]. 生态学报,2014,34(18):5311 – 5319. [XU Huifang, SONG Tongqing, HUANG Guoqin, et al. Spatiotemporal variation of soil moisture under different land use types in a typical karst hill region[J]. Acta Ecologica Sinica,2014,34 (18):5311 – 5319.]

Spatial and temporal variability of soil moisture on slope land of different vegetation of dry-hot valley in Jinsha River

HAN Jiao-jiao[1,2], DUAN Xu[1,2], ZHAO Yang-yi[1,2]

(1 *College of Ecology and Soil & Water Conservation, Southwest Forestry University, Kunming* 650224, *Yunnan, China*;

2 *Yuxi Forest Ecosystem Research Station, China's State Forestry Administration, Kunming* 650224, *Yunnan, China*)

Abstract: In order to explore the influence of typical forest grass vegetation on soil moisture change on sloping land in dry hot valley area, the soil moisture content (within the depth of 0 to 100 cm) were collected and measured using the grid sampling method and soil auger method in the drought season in July to December 2016 and rainy season in April 2017, taking the *Leucaena* Benth forest land, *Dodonaea angustifolia* shrub land and *Heteropogon cantortus* grassland as the research objects at dry-hot valley of Juna small watershed in Jinsha River, Yunnan Province, China. The dynamic characteristics of soil moisture under typical forest vegetation in the slope area were analyzed with geostatistics method. The soil moisture content in the dry-hot valley of Jinsha River was low (which were 7.44% in the dry season and 9.88% in the rainy season for the forest land; 10.25% and 10.31% respectively for the shrub land; and 5.03% and 10.60% respectively for the grassland), the soil moisture in the rainy season was higher than that in the dry season, and the soil moisture content in the shrub land was bigger than that in the grassland which was bigger than that in the forest land regardless of the dry season or the rainy season, showing a moderate to strong variation (between 0.07 to 0.28). The soil moisture in the hot valley of Jinsha has significant spatial structure and spatial continuity, and the soil moisture had similar spatial autocorrelation regardless of the season (drought season or rainy season) and the land cover (forest or shrub or grass vegetation). All the autocorrelation coefficients went from positive to negative but with a different lagging distance in the transformation and it was bigger in the rainy season than that in the dry season, demonstrating a moderate to strong spatial autocorrelation. The spatial structure of soil moisture was different depending on the types of land cover and this difference was remarkable in the dry season. The moisture distribution in the deep soil was more complex than that in the surface layer, displaying an obvious patched or stripped distribution with unset high water content areas and low water content areas. The best fitting model was the spherical model for the forest land, shrub and grassland. Under the same land cover, the spatial structure of the water content was similar regardless of dry season or rainy season. In short, different type of land cover will change the spatial distribution of soil moisture in the areas and the rainfall will amplify this difference, but soil moisture still has some spatial continuity. Therefore, diverse strategies in the utilization of water resources should be adopted during ecological restoration and vegetation reconstruction in dry-hot valley.

Key words: dry-hot valley; soil moisture; spatial and temporal variability; vegetation; geostatistics